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JEAB *AT 50: COEVOLUTION OF RESEARCH AND TECHNOLOGY*

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Evidence of how behavioral research and technology have evolved together abounds in the history of the *Journal of the Experimental Analysis of Behavior (JEAB).* Technology from outside the discipline (exogenous), from such disciplines as electronics and computer science, has been adapted for use in behavioral research. Technology from within the discipline (endogenous) has developed from both basic behavioral research and existing apparatus. All of these sources of technology have contributed to the corpus of behavioral research as it has evolved in *JEAB.* Such research, in turn, has provided the environmental pressure necessary for continuing technological evolution both within and outside the discipline. The new technology thus evolved further spurs research along in novel directions. This dynamic coevolutionary interplay between research and technology is an important variable in the past, present, and future of *JEAB.*

Key words: research, technology, coevolution, history, apparatus, programming, Skinner box, contingencies

With this issue, the *Journal of the Experimental Analysis of Behavior (JEAB)* celebrates 50 years as the flagship journal for the scientific movement that began in the early 1930s with B. F. Skinner's revolutionary experiments on what was to become operant conditioning. Skinner's unique conceptual and methodological twists on such psychological issues as extinction, inhibition, discrimination, differentiation, and motivation facilitated by novel research methods and apparatus, gave rise to other questions. These questions in turn branched into others. It was this accumulating momentum of inquiry that ultimately gave rise to the birth of *JEAB* in 1958. Evolution in two realms has occurred in concert over the years since. One is in the substantive content of the research. The other is in the technology supporting that research.

As in other sciences, the relation between these two activities in the experimental analysis of behavior is an intimate one. Technology both enables and constrains scientific research by providing access to methods and data and by pushing or pulling scientific investigation in directions consistent with its use. Technology, however, can do far more than this: in the hands of an astute observer its successes and failures shape the course of subsequent research. Skinner (1956/1960), for example, documented how his research agenda evolved in no small part as a function of the shaping of his scientific behavior by technological (apparatus) failures:

> …as soon as you begin to complicate an apparatus, you necessarily invoke a fourth principle of scientific practice: Apparatuses sometimes break down. I had only to wait for the food magazine to jam to get an extinction curve. At first I treated this as a defect and hastened to remedy the difficulty. But, eventually, of course, I deliberately disconnected the magazine. I can easily recall the excitement of that first complete extinction curve … . (1956/1960, p. 110)

Reflecting on his work with Skinner on *Schedules of Reinforcement*, Ferster (1970) noted that ''[t]he physical arrangements of the laboratory, the supplies, the equipment, and the shop were important factors in determining the kind of research that went on'' (p. 39).

Technology serves other functions as well: It contributes to the formation of critical concepts and to organizing and integrating research. Jenkins (1979) observed that ''[i]t is hard to overestimate the influence of experimental arrangements on the shape of a learning theory. The maze, runway, and puzzle box do not suggest shaping, which is the operationalization of response-selection by reinforcement'' (p. 200). Indeed, Skinner's (1935) conceptualization of the operant coincided with the development of a technology for recording repeated instances of a response class wherein the comprising individual re-

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sponses were not necessarily topographically identical, but had identical effects on the environment. It is difficult to sort out to what extent the concept of the operant was the impetus for its observation and measurement with a switch, and to what extent the observation and measurement of the response led to the concept of the operant. Philosophers of technology come down on both sides of the question of how scientific concepts and technology influence one another (e.g., Baird, 2004; Daumas, 1964). What is clear is that conceptual and technological/empirical advances go together hand-in-glove. Dinsmoor (1988) noted this relation as follows: ''(t)he abstract category 'response' serves an integrative function at the theoretical level, and in a somewhat different fashion the concrete instance of a switch closure serves to integrate the data at an empirical level'' (p. 288).

The technology associated with research in *JEAB* drew both from technologies developed in other arenas of discovery and application (*exogenous* technology), and from within the discipline (*endogenous* technology). Two points concerning these categories warrant comment. First, ''in the discipline'' is taken here to mean ''within all areas of psychology,'' not just the experimental analysis of behavior. The origins of the rat lever may be lost in the corridors of time, but it is known that early ''brass instrument'' psychology used telegraph keys and other electrical switching devices. It does not seem unreasonable to speculate that such a psychological context contributed to the appearance of a rat *lever,* as opposed to a device for measuring another response class. Is the rat lever, then, endogenous or exogenous (after all, it does involve a fulcrum) in its origins? This raises the second point: the distinction between exogenous and endogenous sometimes is blurred and therefore somewhat arbitrary. Skinner's creative early research apparatus, including the rat lever, for example, depended on developments in such areas as electronics and electrical engineering, mechanics, and experimental physiology. Similarly, much of the apparatus used in experiments described in *JEAB* over the past 50 years has involved hardware originally designed for other applications. Manual switches, relays, transistors, and integrated circuits are content free: their primary function is to channel electricity hither and thither as circumstances demand. Once these technologies were harnessed for use in behavioral experiments, however, the subsequent evolution of the technology depended in part on the demands of studying specific behavioral phenomena.

Over *JEAB*'s 50-year history, behavioral research and technology, to borrow a description from evolutionary biology, coevolved. Coevolution is said to occur when there is reciprocal evolutionary change in two different species or, by extrapolation (or analogy) to the present case, interacting entities or systems. This coevolution of exogenous and endogenous technology with research in the experimental analysis of behavior is a significant component of the past, present, and future of *JEAB*.

Exogenous Technology

The topic of every research article in *JEAB* has been behavior, more or less precisely measured, recorded, analyzed, and then interpreted. In *Behavior of Organisms* Skinner (1938) noted that ''the movement of the lever is recorded electrically *as a graph of the total number of responses plotted against time* [italics added]'' (p. 59). Skinner imported the kymograph from experimental physiology and harnessed it to his purposes of creating these cumulative records, as his graphs came to be known (Coleman, 1987; Lattal, 2004; Skinner, 1956/1960). There is no mention of digital recording of responses in the book. It appears that in those instances where response counts are given (e.g., Figure 67, p. 208) the data could have been derived from the cumulative records. Murray Sidman (personal communication, May 11, 2007) recalled that digital electrical impulse counters were not used in the early days of his graduate education at Columbia University, circa 1950, though they did appear later during his time there. In describing ''The use of the free-operant in the analysis of behavior,'' Ferster (1953) devoted almost two journal pages to describing cumulative recording of responses, but digital electrical impulse counting of responses is not mentioned. Cumulative records were the only data presented in Ferster and Skinner's (1957) encyclopedic analysis of schedules of reinforcement; however, response counts and even interresponse time distributions appeared in published research articles well before 1957. The first article in *JEAB* to *explicitly* mention the use of digital electrical impulse counters was Conrad, Sidman, and Herrnstein (1958). Eighteen years later, Skinner (1976) eulogized the passing of the cumulative record as a primary means of data analysis, this function having been replaced by the digital electrical impulse counter and, increasingly even then, the digital computer. Electrical impulse counters were used in a host of engineering and other applications long before their appearance in behavioral research. Their importation into the experimental analysis of behavior allowed far more precise quantification of behavioral data than was possible with cumulative records. Such precision resulting from this simple imported technology underpinned Herrnstein's (1970) matching law and the subsequent evolution that followed in *JEAB* of the quantitative and theoretical development of matching, alternatives to matching, and other behavioral phenomena. Indeed, some of the mathematical techniques used in behavior analysis, such as those adapted from the analysis of momentum (Nevin, Mandell, & Atak, 1983) and the detection of signals in noise (signal detection theory: Davison & Tustin, 1978; Green & Swets, 1964; Nevin, 1969) may be considered examples of technologies imported from other areas of endeavor.

The programming of reinforcement contingencies evolved from imported technology. Ferster (1970) described how in the early days of the experimental analysis of behavior ''the typical operant experimenter either manually operated switches in a darkened room or programmed a half dozen relays cannibalized from vending machines'' (p. 37). The evolution of methods for controlling contingencies paralleled the evolution of electronics and computer technology in the broader culture, albeit with a lag between innovations in these fields and their assimilation into the experimental analysis of behavior. Electromechanical relays used in conjunction with timers and counters of various sorts remained the coin of the contingency-programming realm in *JEAB* into the 1970s. The first description in *JEAB* of transistorized (solid state) circuits for behavioral research was that of Weiner (1963), although advertisements for transistorized programming equipment appeared in *JEAB* in 1961. Both electromechanical and transistor technology allowed the study of contingencies that would have been impossible to arrange manually, or to analyze.

A scant two years after Weiner's article on transistorized circuitry, Weiss and Laties (1965) described the programming of a reinforcement schedule using a digital computer. Uber and Weiss (1966) described a method of ''computer control of operant behavior experiments via telephone lines,'' which was developed in part because the cost of a computer in the laboratory was ''still out of the question for most laboratories'' (p. 513). In that same September 1966 issue of *JEAB*, Blough (1966) reported the first experiment in the Journal to use a computer to control the experiment (see also Weiss, Laties, Siegel, & Goldstein, 1966, in the next issue after Blough's article). In the January 1967 issue, the first advertisement for a Digital Corp. LINC 8 computer appeared in *JEAB*. Like the electromechanical and transistorized programming systems that came before them, computers facilitated the evolution of the experimental analysis of behavior in ways not always possible with their predecessors. Their use exemplified Sidman's (1960) discussion of gaining precise control over the environment as a way of understanding the controlling variables of behavior. Computers now are so ubiquitous in the experimental analysis of behavior (though not in applied behavior analysis) that it is rare to see experiments conducted in this tradition in their absence. The benefits to the science of behavior are obvious, as were the benefits of the earlier electromechanical and transistorized technologies; the only question is whether they have come to define the experimental analysis of behavior to an extent that detrimentally precludes the consideration of other methods.

In the case of the exogenous technologies of both counting and computing, their applications in a host of disciplines, including psychology, resulted in further technological evolution that was at least in part in response to their application. Kymographs proliferated into literally hundreds of specialized designs for particular purposes, one of which ultimately was the cumulative recorder. Digital counters became more durable, more reliable, more adapted to particular research niches (e.g., counters that printed their counts on demand), and faster, capable of tracking high speed inputs such as those resulting from a pigeon pecking a key. Computers became increasingly affordable (cf. the Uber & Weiss, 1966, quotation, above), accessible, and user-friendly to scientists, including behavioral ones.

Endogenous Technology

There are at least two aspects of the coevolution of research and technology from within the discipline itself. One is that the basic research of one era becomes the technological pool of procedures and techniques for the next as research questions are answered and controlling variables identified. The other is the form of refinements of apparatus that may both precede and follow the evolution of the research.

Contingencies of reinforcement. The evolved database on reinforcement contingencies in *JEAB* is enormous, and the variation and proliferation of these contingencies represents a rich substrate on which the selection of both research and behavioral technology operates. Reinforcement contingencies as technological applications are particularly illustrative of the coevolution of research and technology, for, typically, it is only as a contingency becomes scrutinized through the research process that the results are available for technological application, be it in ameliorating problems of human behavior or in furthering other basic research. Skinner (1979) noted this interplay of experimental analysis and subsequent technology with respect to his ''Project Pigeon/ORCON'' (Skinner, 1960), a project to develop a pigeon-guided bomb during the Second World War: ''The research that I described in *The Behavior of Organisms* appeared in a new light. It was no longer merely an experimental analysis. It had given rise to a technology [in the project's work]'' (p. 274). Numerous other examples of experimental analyses giving rise to or coevolving with technology can be found.

Although the hand-shaping of responses was not described until 1943 (Peterson, 2004), the notion of response differentiation to which it pertains was a critical part of Skinner's (1938) framework for behavior. Response differentiation, that is, the process whereby an existing response is refined or otherwise changed into another form, subsequently evolved as a defining research area of the experimental analysis of behavior, one approached in different ways over the history of *JEAB*. Shaping, the technological complement to response differentiation, became the technological *sine qua non* for quickly differentiating responses of all types (e.g., Levison, Ferster, Niemann, & Findley, 1964). Shaping as a topic of research in *JEAB* thus reflects both theoretical and technical themes (e.g., Eckerman, Hienz, Stern, & Kowlowitz, 1980; Pear & Legris, 1987). The technology of hand shaping also was generalized to the differentiation of an operant class of responses under Sidman or free-operant avoidance, a procedure whereby aversive stimuli, scheduled at regular intervals and without any exteroceptive stimulus signaling their impending occurrence, are postponed by each instance of that operant response. Establishing the operant response under such a contingency is complicated because of the absence of any immediate consequence following the response. One solution, in the early days of *JEAB*, was to place the rat in the chamber and hope for acquisition as the animal was exposed to the avoidance contingency. Some animals learned the response, others did not. Baron (1991) subsequently described a procedure for shaping free operant avoidance that reportedly results in a high proportion of animals developing responding under the Sidman avoidance contingency.

Brown and Jenkins (1968) reported that key pecking by pigeons could be developed by preceding food delivery with a brief (e.g., 6 s) illumination of an otherwise dark response key (cf. Skinner, 1971). The phenomenon, labeled ''autoshaping,'' and the related phenomenon of negative automaintenace, whereby key pecking under an autoshaping procedure continues even though such responses cancel the forthcoming food delivery (Williams & Williams, 1969), were at the vanguard of the study of biological constraints on learning in the 1970s (cf. Domjan & Galef, 1983; Schwartz, 1974). The development of autoshaping along theoretical lines (e.g., McSweeny, Ettinger, & Norman, 1983; Williams, 1983) coevolved with its widespread use as a technology for the automated development of some forms of operant behavior and a preparation for the study of respondent conditioning (e.g., Rescorla, 2002).

There are different paths in the evolutionary tree of the extensive schedule-of-reinforcement research reported in *JEAB* over the past 50 years. One is that of analyzing the controlling variables of schedule performance; another is that of considering schedules as fundamental determinants of behavior in the sense that ''reinforcement schedules establish rates and patterns of responding, and these historical effects then determine how other variables modulate behavior'' (Zeiler, 1984, p. 487). These two paths have different theoretical implications (e.g., Zeiler), but as research along either of these paths has evolved, so has the adapting of the schedules and their parameters to the experimental analysis of many behavioral processes, that is, as a technology for establishing baselines for the analysis of other behavioral, pharmacological, and neurological phenomena. For example, Catania and Reynolds's (1968) comprehensive analysis of responding on interval schedules of reinforcement was a significant contribution to reinforcement theory, but also to the use of interval schedules as baselines for the analysis of other behavioral processes.

In the spirit of the subtitle of this review, it also is the case that behavioral technology can lead to new research. For example, conducting experimental sessions followed by postfeeding the subjects to maintain their body weights within a designated range was a well-established technology that developed long before *JEAB* existed. Subsequent research in *JEAB* modified this technical practice of postfeeding experimental animals by simply requiring that all food be earned in the experimental situation, thereby creating a closed, as opposed to the postsession-feeding open economy. Reassessing, and then modifying, this technology contributed to the development of behavioral economics, an important area of theoretical development in contemporary behavior analysis (e.g., Green & Freed, 1998; Hursh, 1978).

Apparatus. Mention ''*JEAB*'' and ''apparatus'' in the same sentence to any psychologist and the association is likely to be ''Skinner box,'' a label not preferred by Skinner but the one almost universally assigned to his operant conditioning chamber. Skinner (1956/1960) described the evolution of this apparatus from straight alley to enclosed experimental space. The first chambers were designed for rats and the same design principles later were manifest in chambers that evolved for other species: pigeons, primates, insects, fish, and even humans. In line with Jenkins's (1979) observation quoted previously, the operant chamber both premiered and stimulated a particular methodological approach, reflecting a fundamental concern with analysis based on the isolation of controlling variables. These methods in turn invited a conceptual orientation emphasizing that these controlling variables were to be found in the environment thus created—in the manipulation of the antecedent stimuli enabled by the apparatus and the consequences that were so neatly arranged in the operant conditioning chamber.

The programming of contingencies has undergone extensive changes since that first issue of *JEAB*, but the operant chamber in more or less its original form has survived as a useful tool,

> a kind of 'preparation,' like Sherrington's for the study of spinal reflexes or Thomas Hunt Morgan's for the study of genetics. A species of organism is chosen and a standard space constructed. A corpus of facts about the organism is accumulated so that further research in a similar space need not start from scratch. (Skinner, 1986, p. 230)

Even though extrapolating into settings involving multiple responses (e.g., Findley, 1962), social interactions (e.g., Hake & Schmid, 1981; Kelly, Hienz, Zarcone, Wurster, & Brady, 2005; Schmitt, 2000), and nonconventional laboratory environments in which humans live for extended time periods (e.g., Bernstein & Ebbesen, 1978; Emurian, Emurian, Bigelow, & Brady, 1976) has required adaptations of the ''preparation'', its basic elements have remained recognizable, if not intact.

Some of the individual components of rat and pigeon chambers likewise have remained constant over the years of *JEAB*'s existence, but others have been adapted in various ways that increase experimental control. The response keys for pigeons described by Ferster and Skinner (1957) the year before *JEAB* began publishing are basically the same as ones in use today (in fact, at least some of those original response keys are still in use). Pellet dispensers for use with rats are powered differently, as a function of changes in electronics, but still are basically the same design as some of Skinner's early ones. Grain hoppers for pigeons have evolved into a form that minimizes the possibility of injury to the pigeon and the unauthorized eating outside the food delivery cycle. Stimuli remain primarily lights and sounds, though imported computer technology has greatly increased the flexibility of presenting complex stimuli. Throughout the pages of this Journal, there have been many descriptions of how components for all of the aforementioned functions have been adapted in myriad ways to allow the study of behavioral phenomena.

Past, present, and future. Examples of the coevolution of research and the technology of the times are replete in the research described in the 288 issues of *JEAB* published prior to this anniversary issue. In many circumstances, technology has provided the tools necessary for an experimental analysis to proceed, including the standardization of procedures that plays a critical role in replication (cf. Sidman, 1960). Behavioral research not only has benefited from technology, but also has contributed to the further development of both exogenous and endogenous technology. Just as technology is adapted to research purposes, research needs often provide the environmental pressure necessary for the selective evolution of technological solutions for the research-driven problem. The new technology thus evolved can further spur research along in novel directions. Such a dynamic interplay between research and technology is an important variable in the history of *JEAB*.

Any technology adapted to research evokes the asking of certain kinds of questions. The body of research represented in *JEAB* certainly attests to the benefits of these adaptations. On the one hand, however, there are risks to such adaptations if and when the research comes under the control of the technology rather than the subject matter. Skinner (1979) noted the problem as follows with respect to his own research in the years following the publication of *Behavior of Organisms:* ''These were a kind of technological application of the operant methodology. I was *using* an experimental analysis of behavior rather than furthering it. The results were interesting to many more people, but they were digressive'' (p. 343). On the other hand, what is digressive to one scientist may be a fruitful new direction for another. Furthermore, Skinner's problem of stagnation also can occur when research remains in the hands of Luddites, failing to adapt technological innovations where it could be advantageous to do so. The experimental analysis of behavior is best served when technology is neither prison nor prisoner.

There is an endless dance between the behavioral research published in *JEAB* and the technology that has supported it. It is a dance rich in tradition, sometimes awkward, but with allowances for innovation and adaptation to novel, unexpected changes in rhythms both within and outside the discipline. It has both elegance and vitality. It is beautiful to watch, but even lovelier to be a participant. In the inductive tradition that characterizes the research in *JEAB*, we must await the data to see where the intermingled processes of research and technology next take the experimental analysis of behavior. Based on the past 50-year history, however, there is every reason to expect the research reported in *JEAB* will evolve in concert with its technology partner as the dance continues…

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